

# GROUND WATER HYDROLOGY

# Learning Objectives

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1. Ground Water Occurrence
2. Types of Aquifers
3. Aquifer Parameters
4. Darcy's Law
5. Measurement of Coefficient of Permeability of Soil
6. Types of Wells
7. Well Construction
8. Well Development

# Ground Water Occurrence

**Groundwater** is water that exists in the pore spaces and fractures in rocks and sediments beneath the unsaturated zone of soil which can flow freely into a well, tunnel, spring etc.

Groundwater occurrence mainly depends on

- Porosity
- Saturated and Unsaturated Zones
- Permeability of soil
- Aquifer
- Storage Coefficient

# Types of Geological Formations

There are basically four types of geological formations

1. Aquifers
2. Aquitard
3. Aquiclude
4. Aquifuge

# Aquifer

**An aquifer** is a ground-water reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in a usable quantity to wells and springs.

Sand and gravel deposits, sandstone, limestone, and fractured, crystalline rocks are examples of geological units that form aquifers.

Aquifers provide two important functions:

- 1) To transmit ground water from areas of recharge to areas of discharge
- 2) To provide a storage medium for useable quantities of ground water

The amount of water a material can hold depends upon its porosity.

# Types of Aquifer

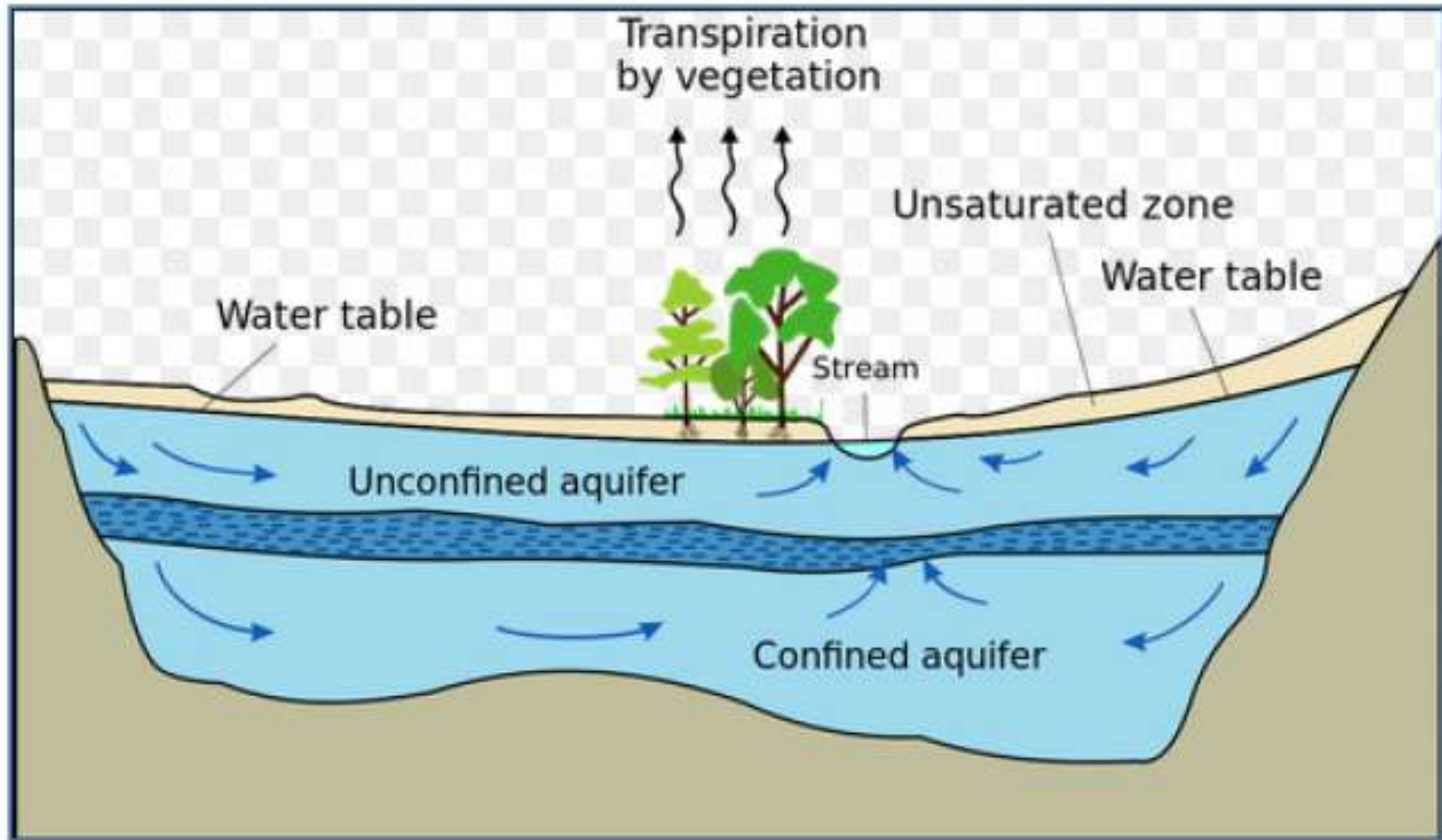
## **Types of Aquifers:**

1. Unconfined Aquifer
2. Confined Aquifer

## **Unconfined Aquifer:**

An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, and permeability.

Contour maps and profiles of the water table can be prepared from elevations of water in wells that tap the aquifer to determine the quantities of water available and their distribution and movement.



# Types of Aquifer

## **Confined Aquifer:**

Confined aquifers, also known as artesian or pressure aquifers, occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata.

Water enters a confined aquifer in an area where the confining bed rises to the surface. Water may also enter by leakage through a confining bed.

Confined aquifers display only small changes in storage and serve primarily as conduits for conveying water from recharge areas to locations of natural or artificial discharge.

# Types of Aquifer

## **2. Aquitard:**

An aquitard is a partly permeable geologic formation. It transmits water at such a slow rate that the yield is insufficient. Pumping by wells is not possible. For example, sand lenses in a clay formation will form an aquitard. Also known as a leaky confining layer.

## **3. Aquiclude**

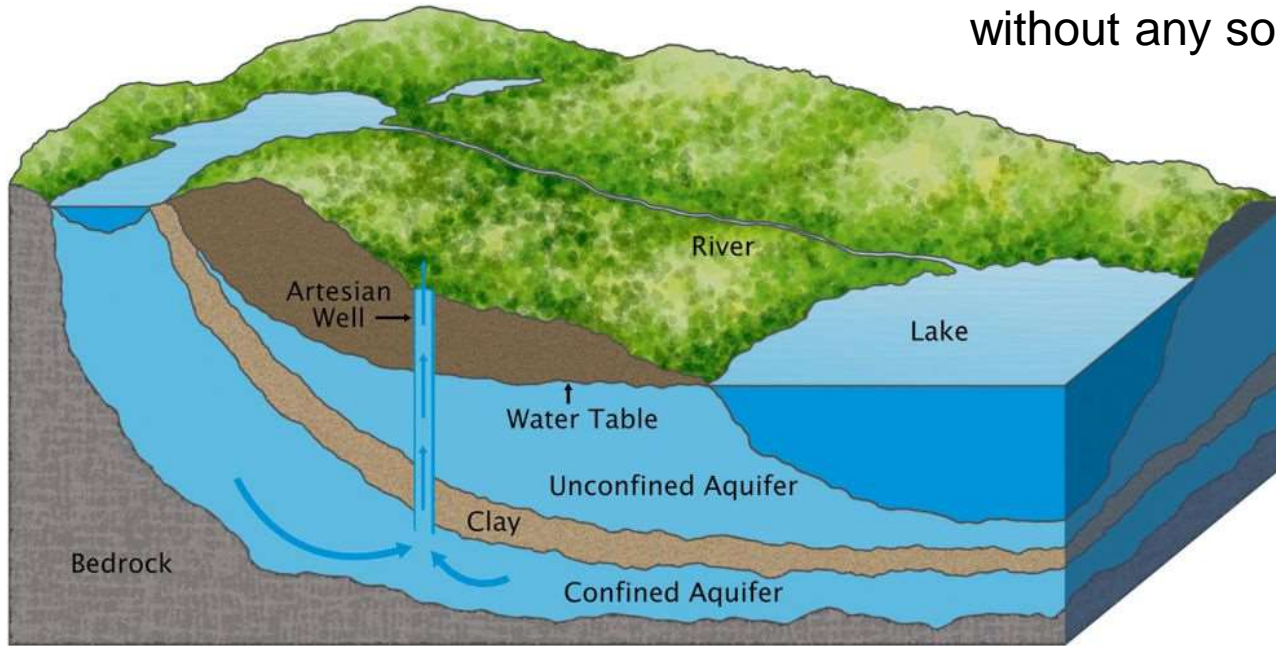
Impermeable layer of soil that may absorb water slowly but does not transmit it. A body of relatively impermeable rock that is capable of absorbing water slowly but does not transmit it rapidly enough to supply a well or spring.

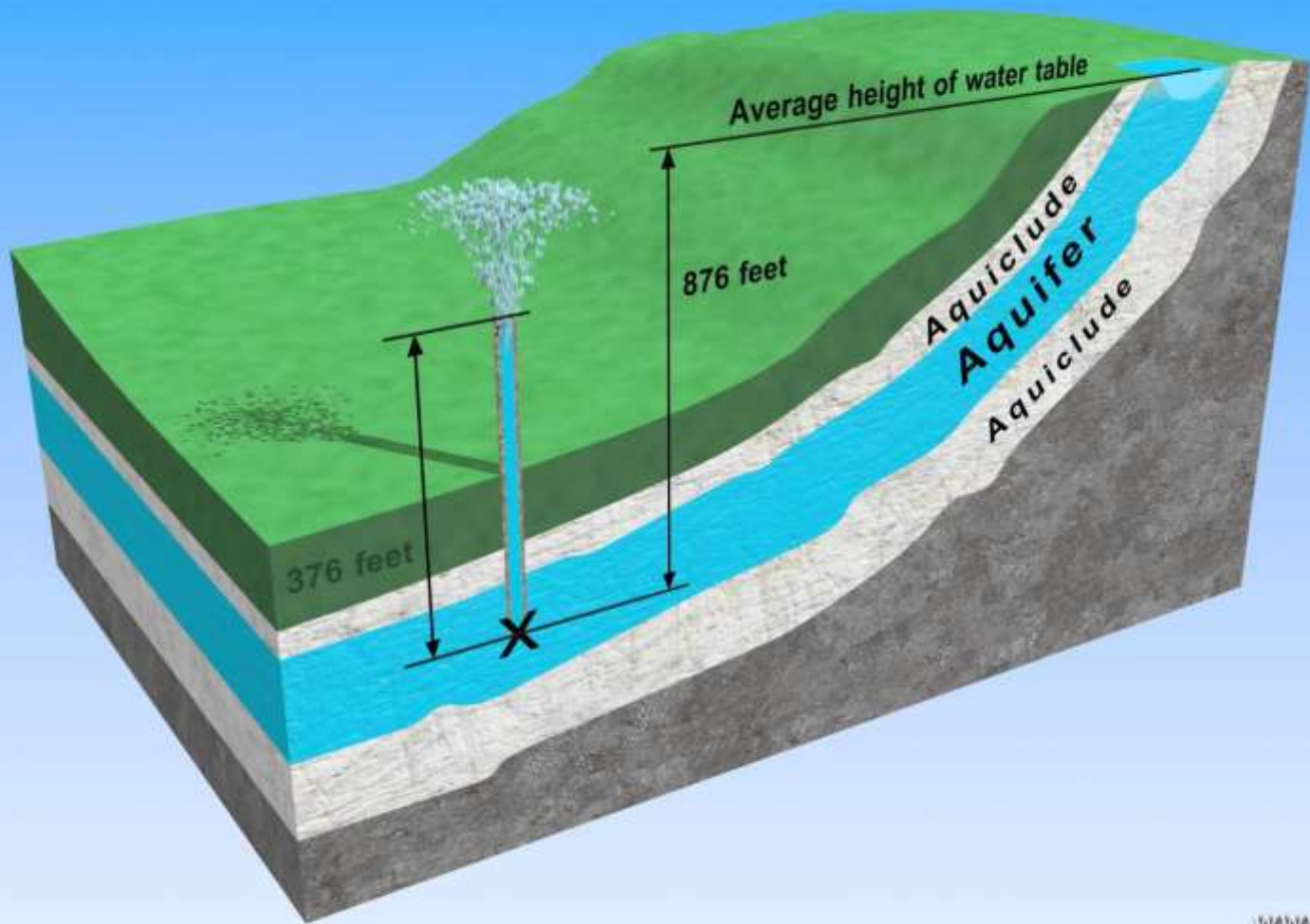
## **4. Aquifuge**

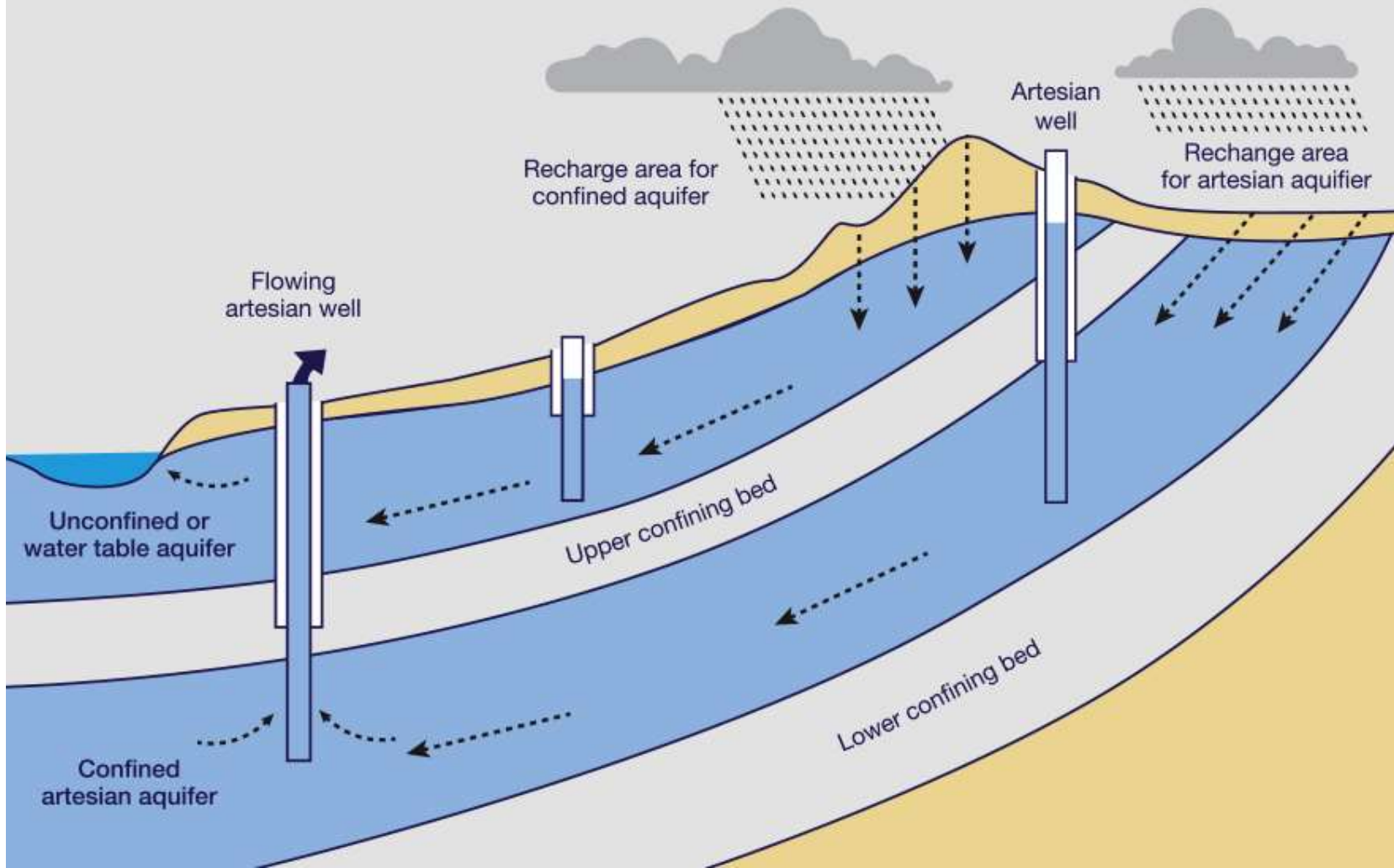
An aquifuge is a geologic formation which doesn't have interconnected pores. It is neither porous nor permeable. Thus, it can neither store water nor transmit it. Examples of aquifuge are rocks like basalt, granite, etc. without fissures.

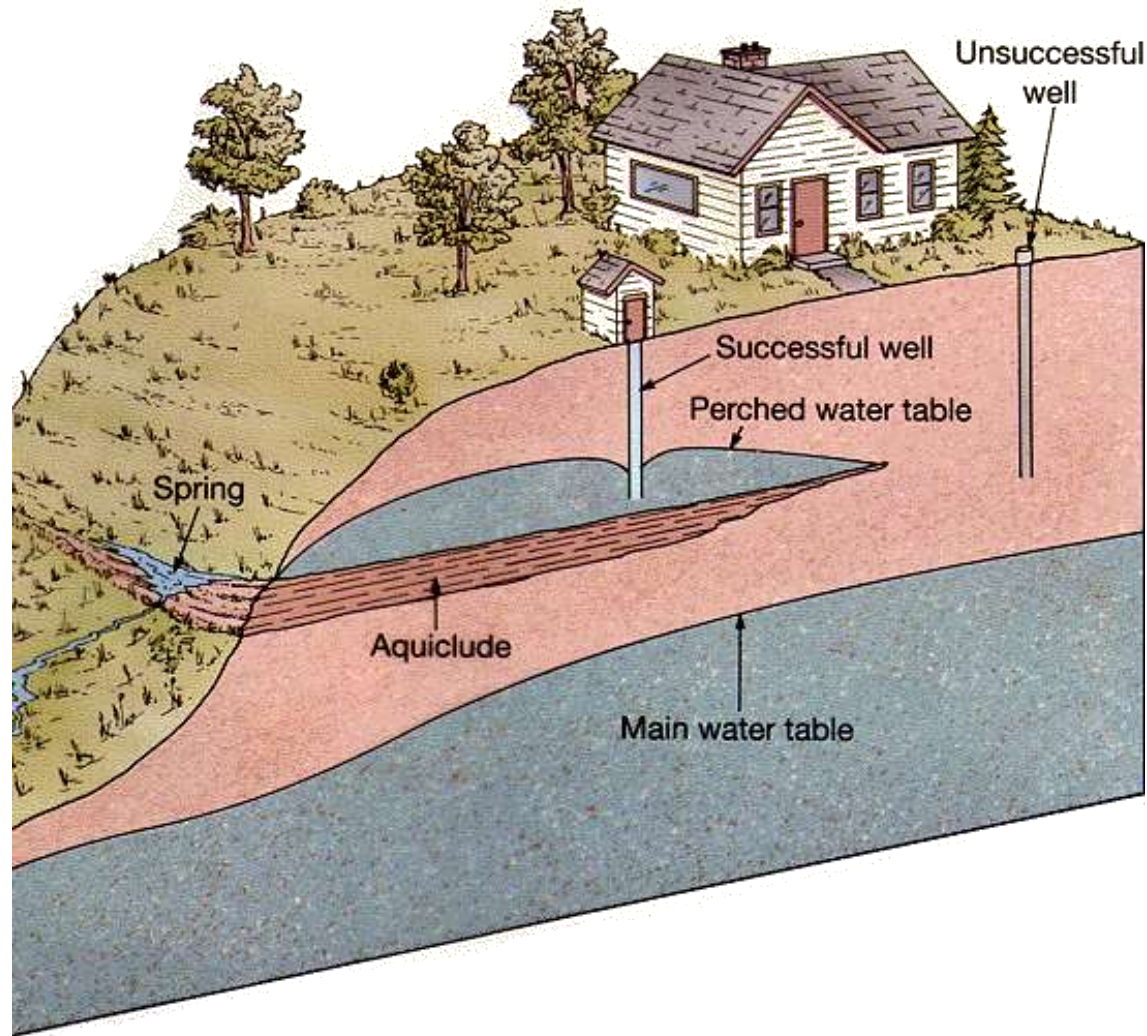
# Aquifer

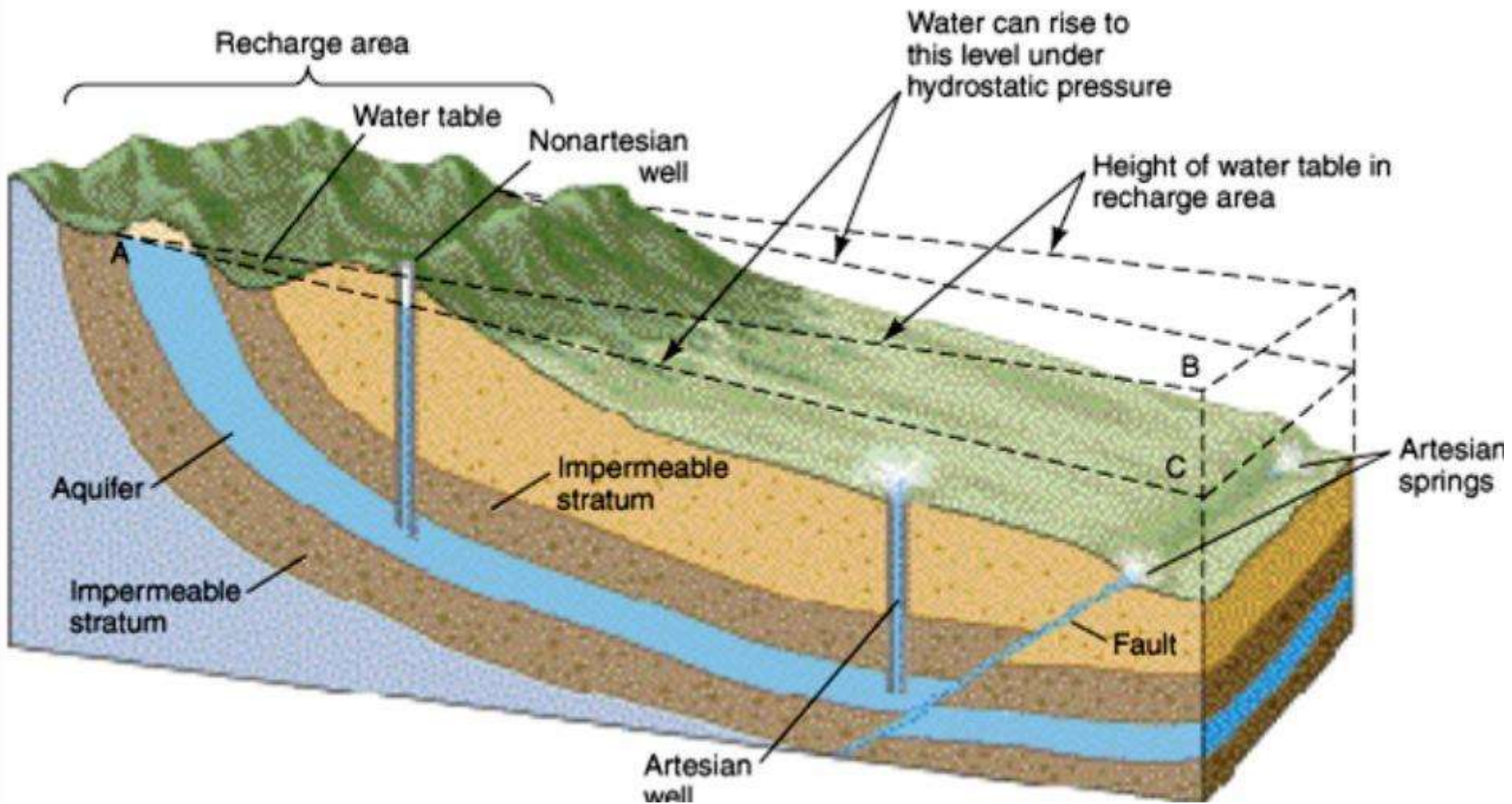
An **artesian well** is simply a **well** that doesn't require a pump to bring water to the surface; this occurs when there is enough pressure in the aquifer. The pressure forces the water to the surface without any sort of assistance

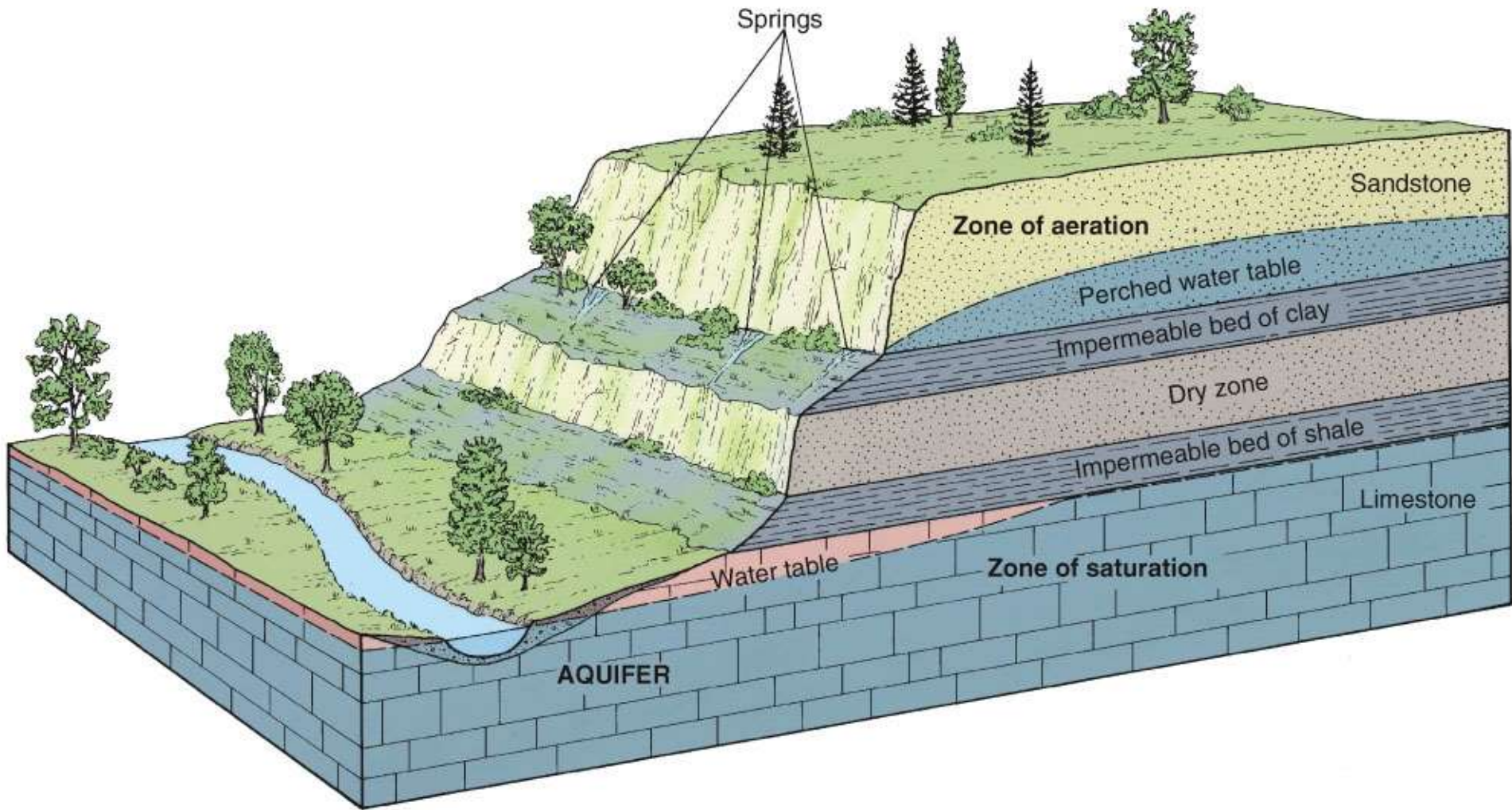












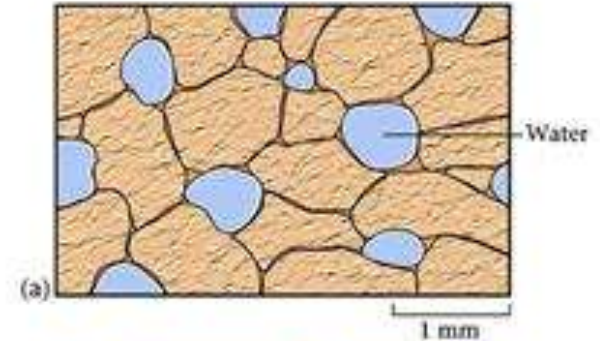
# Aquifer Parameters

## Properties of aquifer:

- 1) Porosity
- 2) Specific Yield
- 3) Specific Retention
- 4) Coefficient of permeability
- 5) Transmissibility
- 6) Specific Storage
- 7) Storage Coefficient

## Permeability & Porosity

Impermeable

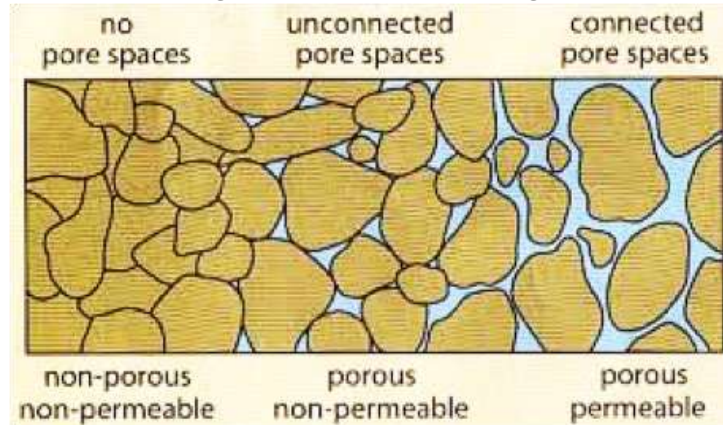


Permeable



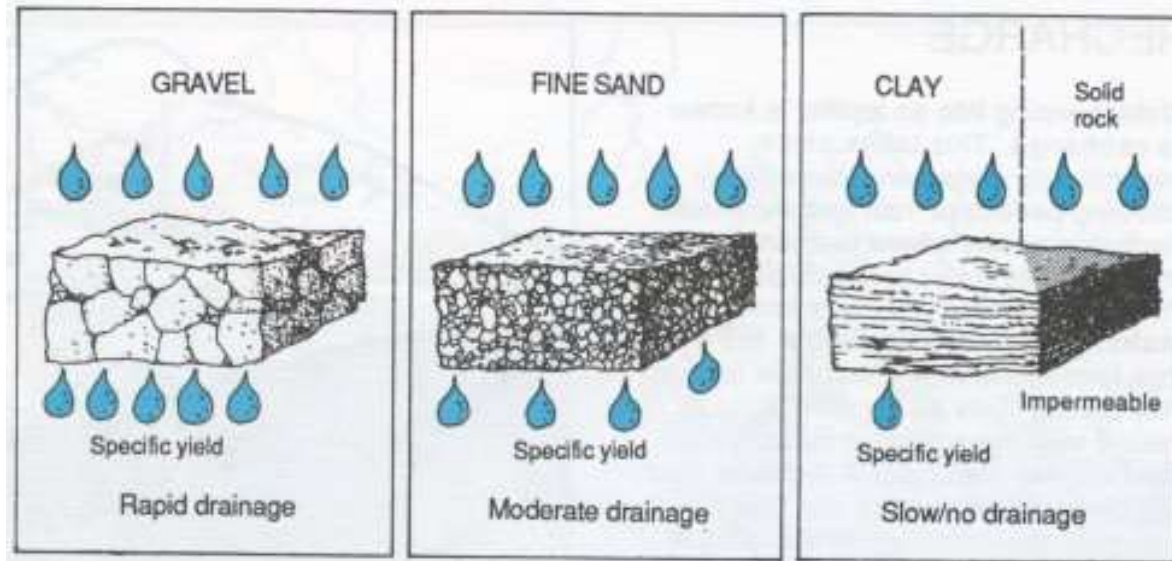
# Aquifer Parameters

- Porosity** - It is the amount of pore, or open space between soil particles.
  - In sediments or sedimentary rocks the porosity depends on grain size, the shape of the grains, the degree of sorting and the degree of cementation.
  - In rocks, the porosity depends upon the extent, spacing and pattern of cracks and fractures.
  - Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments, because the grains don't fit together well



# Aquifer Parameters

**2. Specific Yield** - It is the ratio of the volume of water that drains from groundwater storage due to the attraction of gravity (or by pumping from wells) to the total volume of the saturated aquifer.



# Aquifer Parameters

**3. Specific Retention** – It is the ratio of the volume of water that cannot be drained out to the total volume of the saturated aquifer

- The specific retention increases with decreasing grain size.
- Soil having low permeability may not easily drain out. For example, clay has a high porosity but low specific yield and its permeability is low.

**4. Coefficient of permeability** – It is the ease with which water can flow in a soil mass or rock

The coefficient of Permeability (K) is equal to the discharge ( $\text{m}^3/\text{s}$ ) per unit area ( $\text{m}^2$ ) of soil mass under unit hydraulic gradient. It is usually expressed as  $\text{cm}/\text{s}$ ,  $\text{m}/\text{s}$ ,  $\text{m}/\text{day}$ , etc.

The coefficient of permeability is also called **Hydraulic Conductivity**

# Aquifer Parameters

**5. Transmissibility** - It is the discharge rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

It is usually expressed as  $\text{m}^3/\text{day}/\text{m}$  or  $\text{m}^2/\text{s}$ .

**6. Specific Storage** - It is the amount of water per unit volume of a saturated formation that is stored or expelled from storage.

**7. Storage Coefficient** - It is the volume of water released from storage, or taken into storage, per unit of aquifer storage area per unit change in head.

The storage coefficient is a dimensionless as it is the ratio of the volume of water released from original unit volume. It ranges from 0.02 to 0.30 in unconfined aquifers

# Permeability of soil

**Permeability** is the measure of the soil's ability to permit water to flow through its pores or voids. Knowledge of the permeability properties of soil is necessary to:

- Estimating the quantity of underground seepage
- Solving problems involving pumping seepage water from construction excavation

## **Factors affecting permeability of soil:**

- 1) **Grain size** - Smaller the grain-size the smaller the voids and thus the lower the permeability
- 2) **Void ratio** - Increase in the porosity leads to an increase in the permeability.
- 3) **Composition** - The influence of soil composition on permeability is generally insignificant in the case of gravels, sands, and silts, unless mica and organic matter are present.
- 4) **Soil structural** - Fine-grained soils with a flocculated structure have a higher coefficient of permeability than those with a dispersed structure.
- 5) **Degree of saturation** - Higher the degree of saturation, higher is the permeability.
- 6) **Presence of entrapped air** and other foreign matter reduces the permeability of a soil. Organic foreign matter may choke flow channels thus decreasing the permeability

# Coefficient of permeability of soil

## Measurement of Coefficient of permeability of soil:

### 1. Laboratory Tests (using Darcy's Law)

- a) Constant Head Permeability test - suitable for coarse grained soils,
- b) Falling or Variable Head Permeability test - suitable for fine grained soils

### 2. Field Tests

- a) Pumping Out Tests
- b) Pumping In Tests

### 3. Indirect Methods

- a) Computation from the particle size
- b) Computation from consolidation test

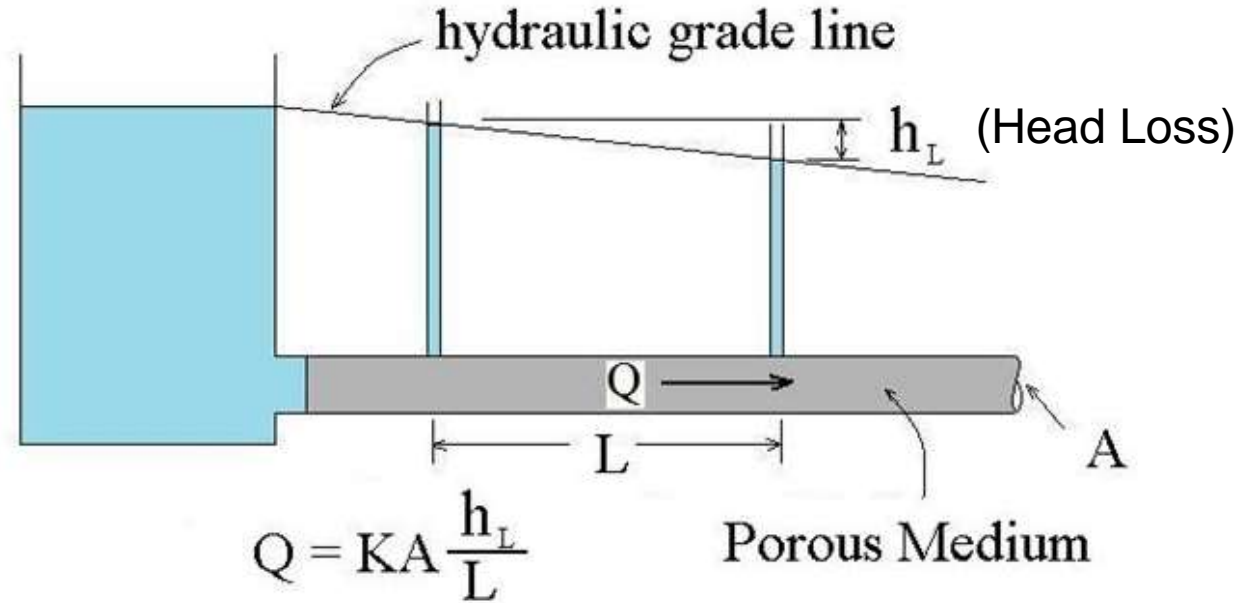
# Darcy's Law

**Darcy's law** is an equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy (1856) based on the results of experiments on the flow of water through beds of sand.

“For laminar flow through saturated soil mass, the discharge per unit time is proportional to the hydraulic gradient”.

## **Assumptions made defining Darcy' law.**

- 1) The flow is laminar i.e., flow follows a definite path and does not cross the path of other particles.
- 2) Water & soil are incompressible i.e., continuity equation is assumed to be valid
- 3) The soil is saturated.
- 4) The flow is steady state i.e., flow condition do not change with time.



Darcy's Law Apparatus

where,

$K$  = coefficient of permeability

$i = h_L/L =$  hydraulic gradient

Typical values of coefficient of permeability for various soils are as follows,

<i>Soil type</i>	<i>Coefficient of permeability (mm/s)</i>
Coarse	$10 - 10^3$
Fine gravel, coarse, and medium sand	$10^{-2} - 10$
Fine sand, loose silt	$10^{-4} - 10^{-2}$
Dense silt, clayey silt	$10^{-5} - 10^{-4}$
Silty clay, clay	$10^{-8} - 10^{-5}$

# Pumping Out Tests

## **Dupuit Theory:**

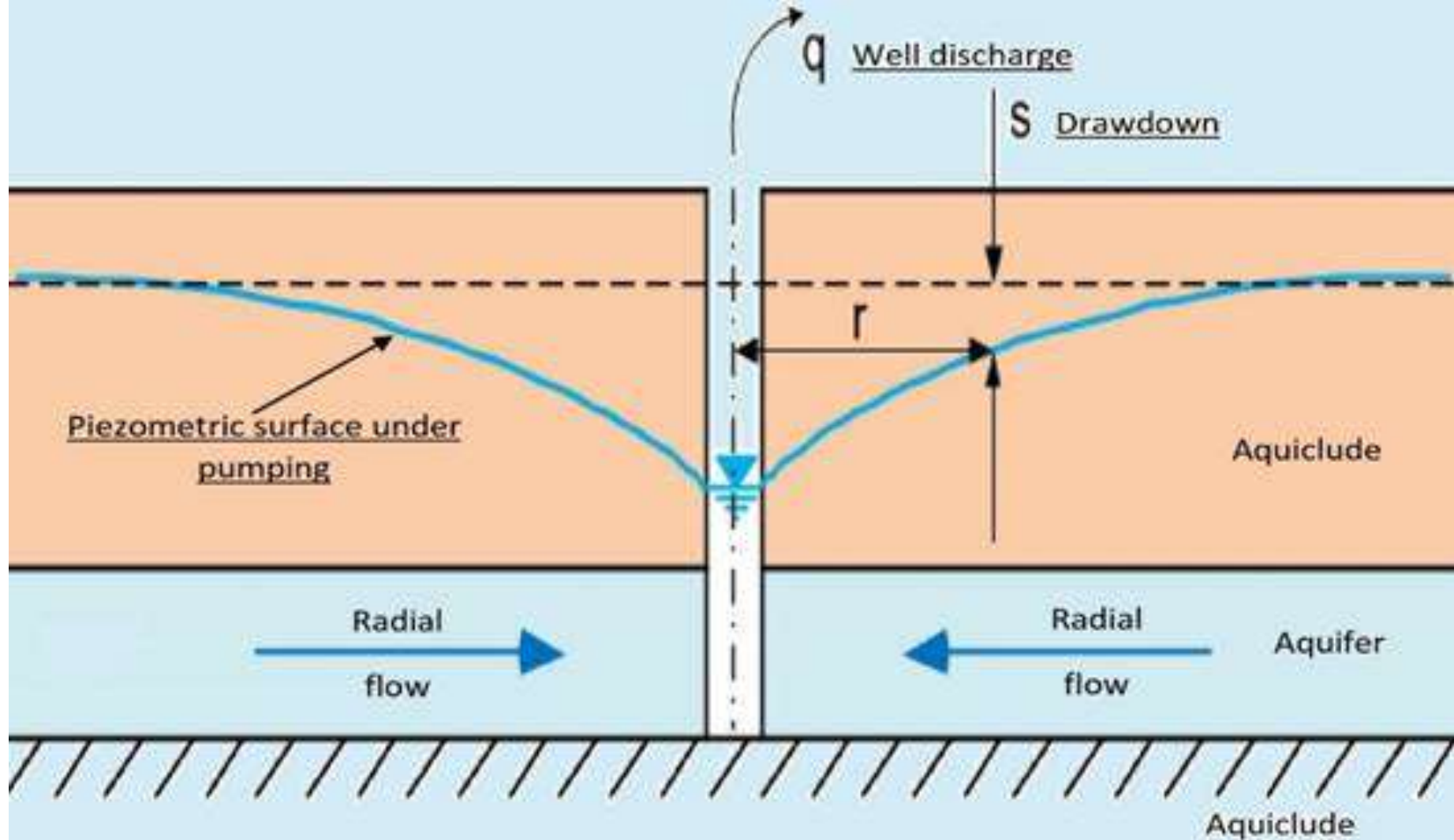
The coefficient of permeability of the permeable layer can be determined by pumping from a well at a constant rate and observing the steady-state water table in nearby observation wells. The steady-state is established when the water levels in the test well and the observation wells become constant. When water is pumped out from the well, the aquifer gets depleted of water, and the water table is lowered resulting in a circular depression in the phreatic surface. This is referred to as the 'Drawdown curve' or 'Cone of depression'.

The analysis of flow towards such a well was given by Dupuit (1863).

# Pumping Out Tests

## Assumptions:

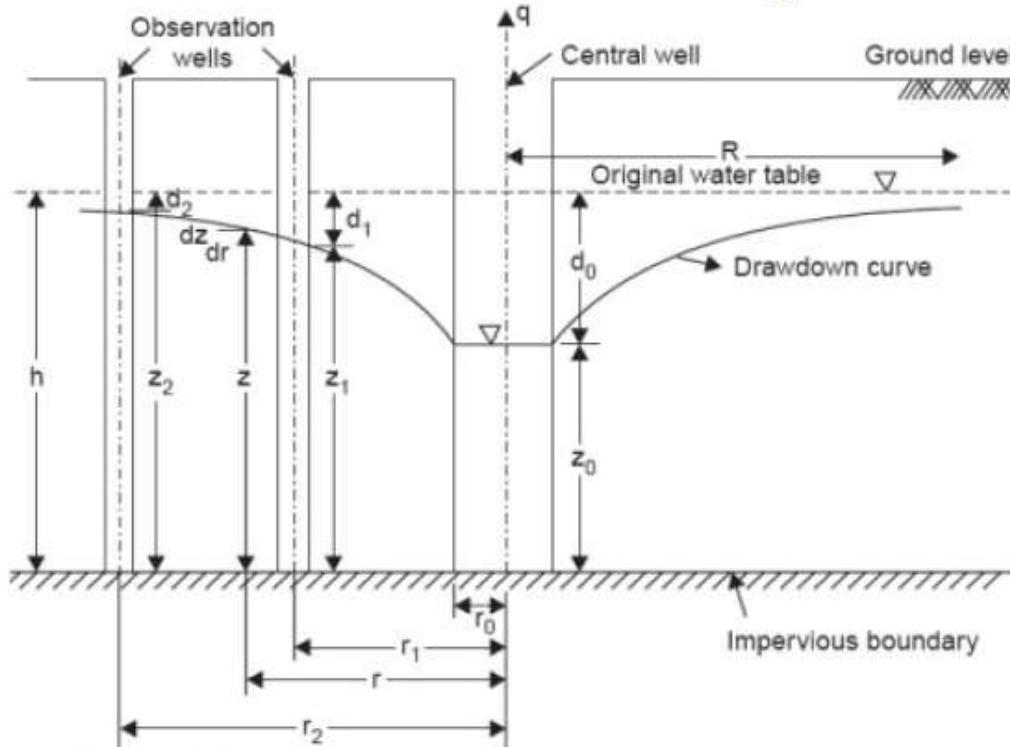
- 1) The aquifer is homogeneous.
- 2) Darcy's law is valid.
- 3) The flow is horizontal.
- 4) The well penetrates the entire thickness of the aquifer
- 5) Natural groundwater regime remains constant with time.
- 6) Dupuit's theory is valid that is,  $i = dz/dr$



### Case 1: Unconfined Aquifer

Let  $r$  and  $z$  be the radial distance and height above the impervious boundary at any point on the drawdown curve as shown in Figure . At steady state, the rate of discharge due to pumping can be expressed as,  $q = kiA$

Hydraulic gradient at any point is given by Dupuit's theory,  $i = \frac{dz}{dr}$



Field permeability test – Pumping out test in an unconfined aquifer

$$\therefore q = k \frac{dz}{dr} 2\pi r z \quad (\because A = 2\pi r z)$$

$$\frac{dr}{r} = \frac{2\pi k}{q} (z \cdot dz),$$

$$\text{integrating both sides } \int_{r_1}^{r_2} \frac{dr}{r} = \frac{2\pi k}{q} \int_{z_1}^{z_2} z \cdot dz$$

$$\Rightarrow k = \frac{2.303q}{\pi(z_2^2 - z_1^2)} \left[ \log_{10} \frac{r_2}{r_1} \right]$$

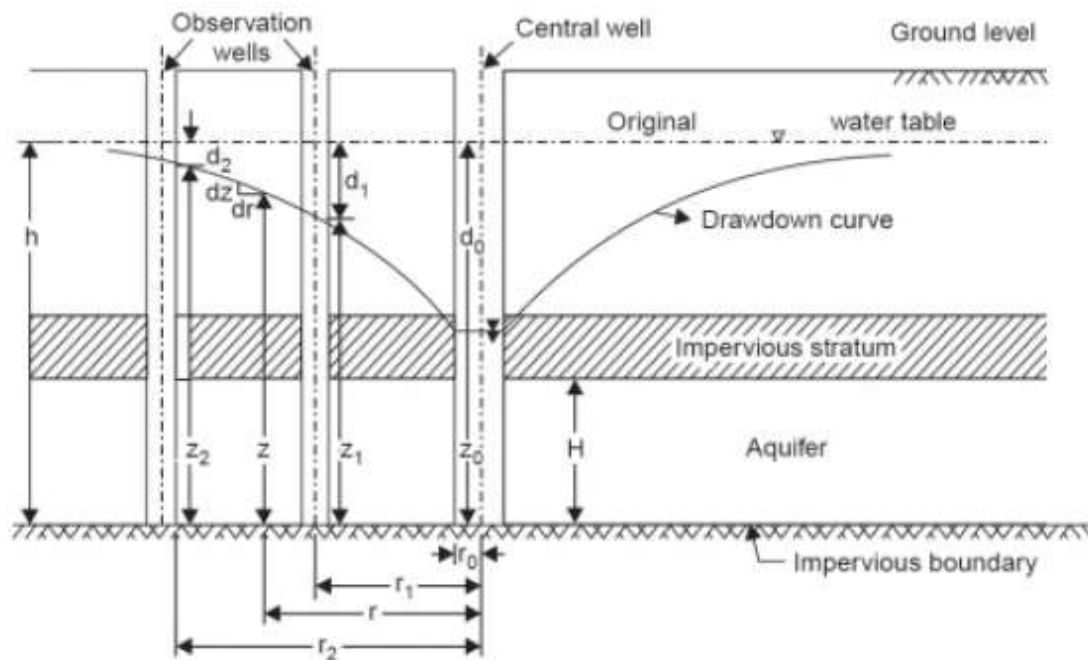
Note:  $z_1 = (h - d_1)$  &  $z_2 = (h - d_2)$

$$\therefore k = \frac{2.303q}{\pi[(d_1 - d_2)(2h - d_1 - d_2)]} \left[ \log_{10} \frac{r_2}{r_1} \right]$$

If the values of  $r_1$ ,  $r_2$ ,  $z_1$ ,  $z_2$ , and  $q$  are known from field measurements, the coefficient of Permeability can be calculated using the above relationship for  $k$ .

## Case 2: Confined Aquifer

Let  $r$  and  $z$  be the radial distance and height above the impervious boundary at any point on the drawdown curve as shown in Figure 4.7. At steady state, the rate of discharge due to pumping can be expressed as,  $q = kiA$



**Field permeability test – Pumping out test in confined aquifer**

$$\therefore q = k \frac{dz}{dr} 2\pi r H \quad (\because A = 2\pi r H)$$

$H$  is depth of confined aquifer

$$k dz = \frac{q}{2\pi H} \frac{dr}{r} \text{ integrating both sides, } k \int_{z_1}^{z_2} dz = \frac{q}{2\pi H} \int_{r_1}^{r_2} \frac{dr}{r}$$

$$\Rightarrow k [z]_{z_1}^{z_2} = \frac{q}{2\pi H} \left[ \log_e r \right]_{r_1}^{r_2}$$

$$\Rightarrow k = \frac{2.303q}{2\pi H(z_2 - z_1)} \left( \log_{10} \frac{r_2}{r_1} \right); \quad \Rightarrow k = \frac{q}{2.7283 \times H(z_2 - z_1)} \left( \log_{10} \frac{r_2}{r_1} \right)$$

Note:  $z_1 = (h - d_1)$  &  $z_2 = (h - d_2)$

$$\therefore k = \frac{q}{2.7283 \times H(d_1 - d_2)} \left( \log_{10} \frac{r_2}{r_1} \right)$$

If the values of  $r_1$ ,  $r_2$ ,  $z_1$ ,  $z_2$ , and  $q$  are known from field measurements, the coefficient of Permeability can be calculated using the above relationship for  $k$ .

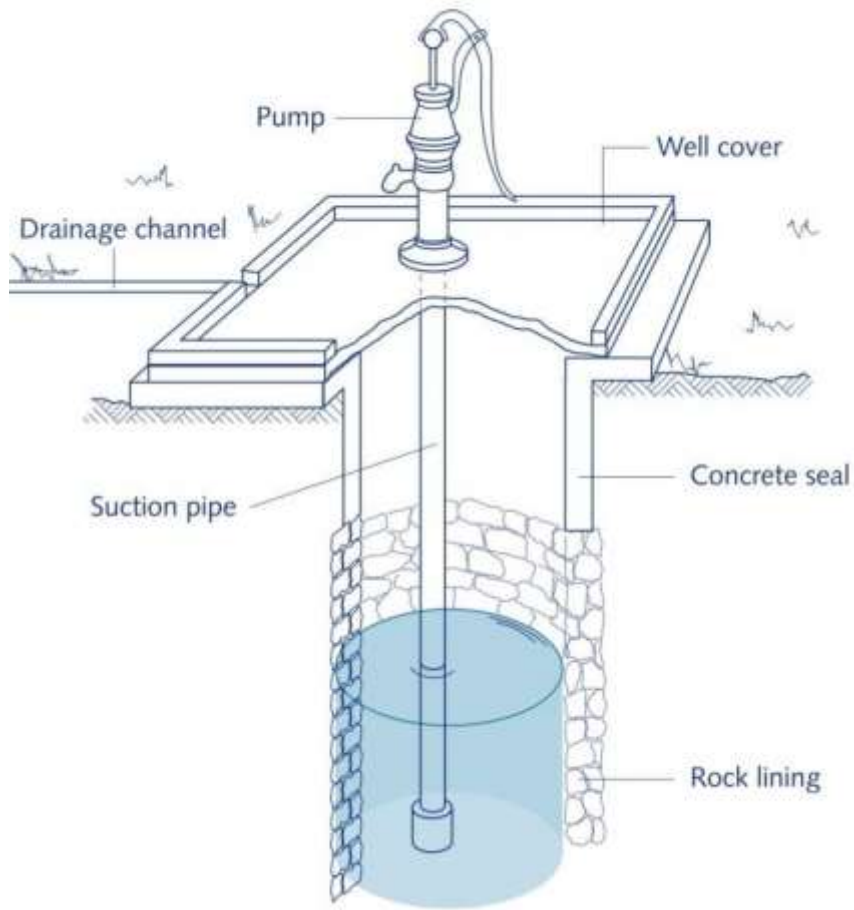
# Types of Wells

## **Types of Water Wells:**

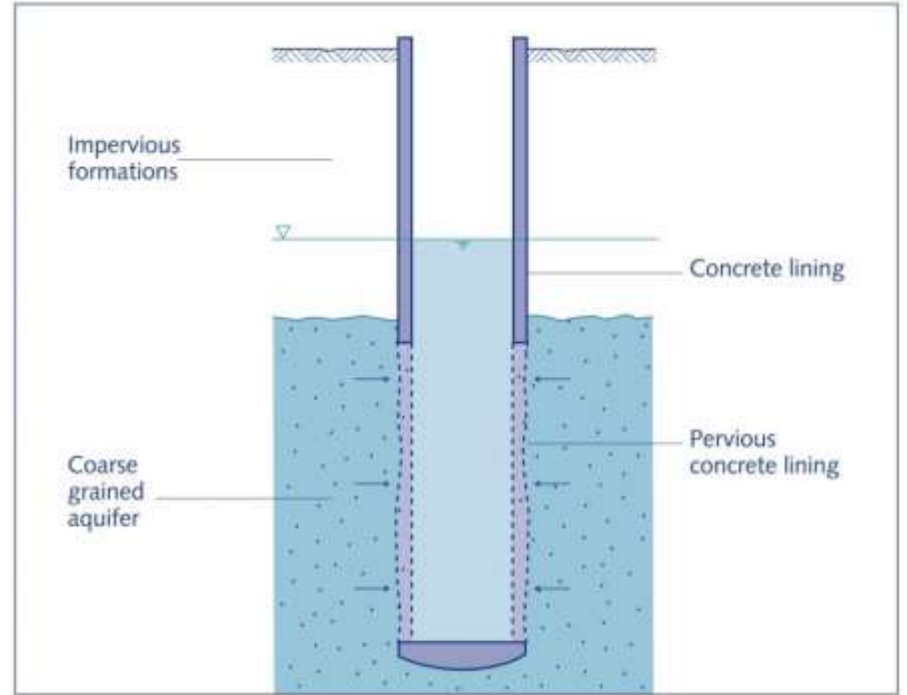
Diverse geological formations require different types of wells for tapping ground water for irrigation and water supply. The choice of type of well for irrigation is influenced by the size of farm holdings and the relative preference given to private, cooperative and public wells.

There are two broad classes of Wells:

1. Dug well / Open wells
2. Tube wells



Dug Well (Rock Lining)



Dug Well (Pervious Concrete Lining)

# Dug well / Open wells

Open wells have been the major means of domestic water supply throughout the span of the recorded history of mankind. They are also used extensively in small-scale irrigation. Compared to tube wells, open wells are shallow and usually used to tap water table aquifers

- Larger diameter (3' to 4')
- Curbing material is usually concrete crocks with loose joints
- Water enters well through loose casing joints.
- Low well yield
- Highly vulnerable to contamination

## **Types of Open wells:**

- a) Unlined wells
- b) Wells with pervious lining
- c) Wells with impervious lining
- d) Dug-cum-Bore wells

# Tube Wells

## Classification based on Entry of water:

- 1) **Screen wells** - The screen permits water to enter the well from the saturated aquifer, prevents sediment from entering the well
  - a) **Strainer Wells** - It essentially consists of a perforated or a slotted pipe with a wire mesh wrapped around the pipe with smaller annular space between the two
  - b) **Slotted pipe gravel pack wells** - It uses a slotted pipe without being covered by any wire mesh
- 2) **Cavity wells** – It is the shallow tube well drilled in alluvial formation. A cavity type tube well draws water from bottom of the well and not from the sides.

# Tube Wells

## Classification based Method of Construction:

### 1) Drilled wells

- a) Constructed using rotary, cable tool, jetting, hollow rod, or auger rigs.
- b) Casing material can be steel or PVC plastic.
- c) Most are greater than 15m deep.

### 2) Driven wells

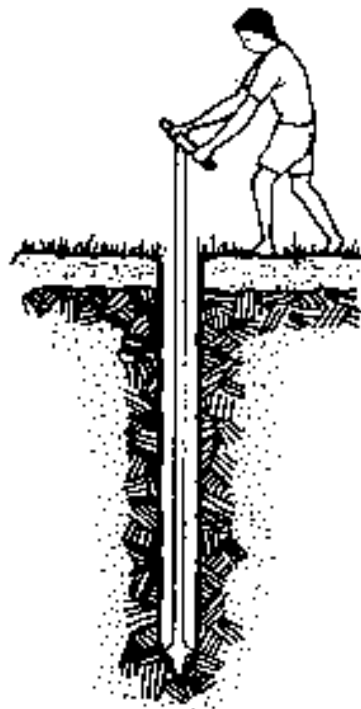
- a) Cannot be driven into bedrock.
- b) Well point driven into ground with post driver, tripod with weight or sledge hammer.
- c) Common around lakes and high water table areas.
- d) Most are less than 10 m deep and have a limited yield (less than 7gpm).
- e) More susceptible to contamination than drilled wells.

**3) Jetted Wells** - Jetted wells are constructed by employing the erosive action of a stream of water to cut a hole, inside which a well screen and rising pipe can be inserted after completion. This type of wells may only be constructed in places where subsoil formations are soft enough to allow the technique to work

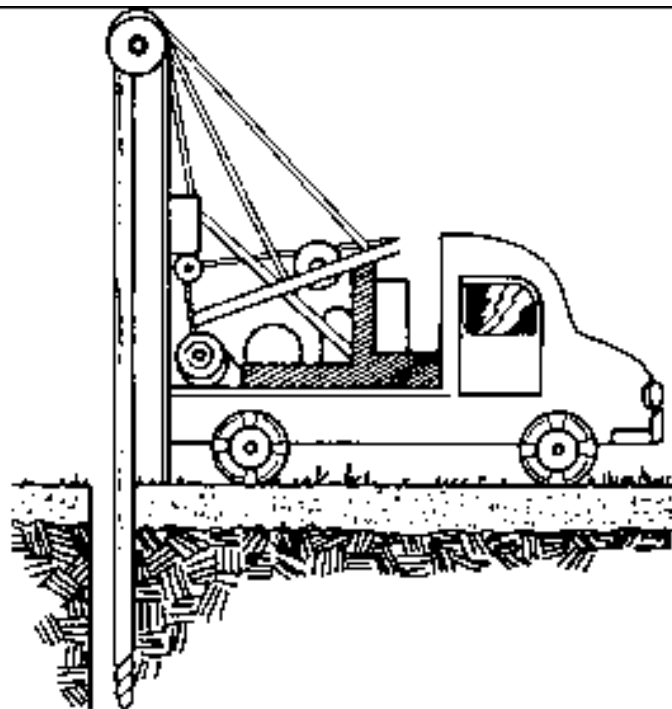
Hand dug Well

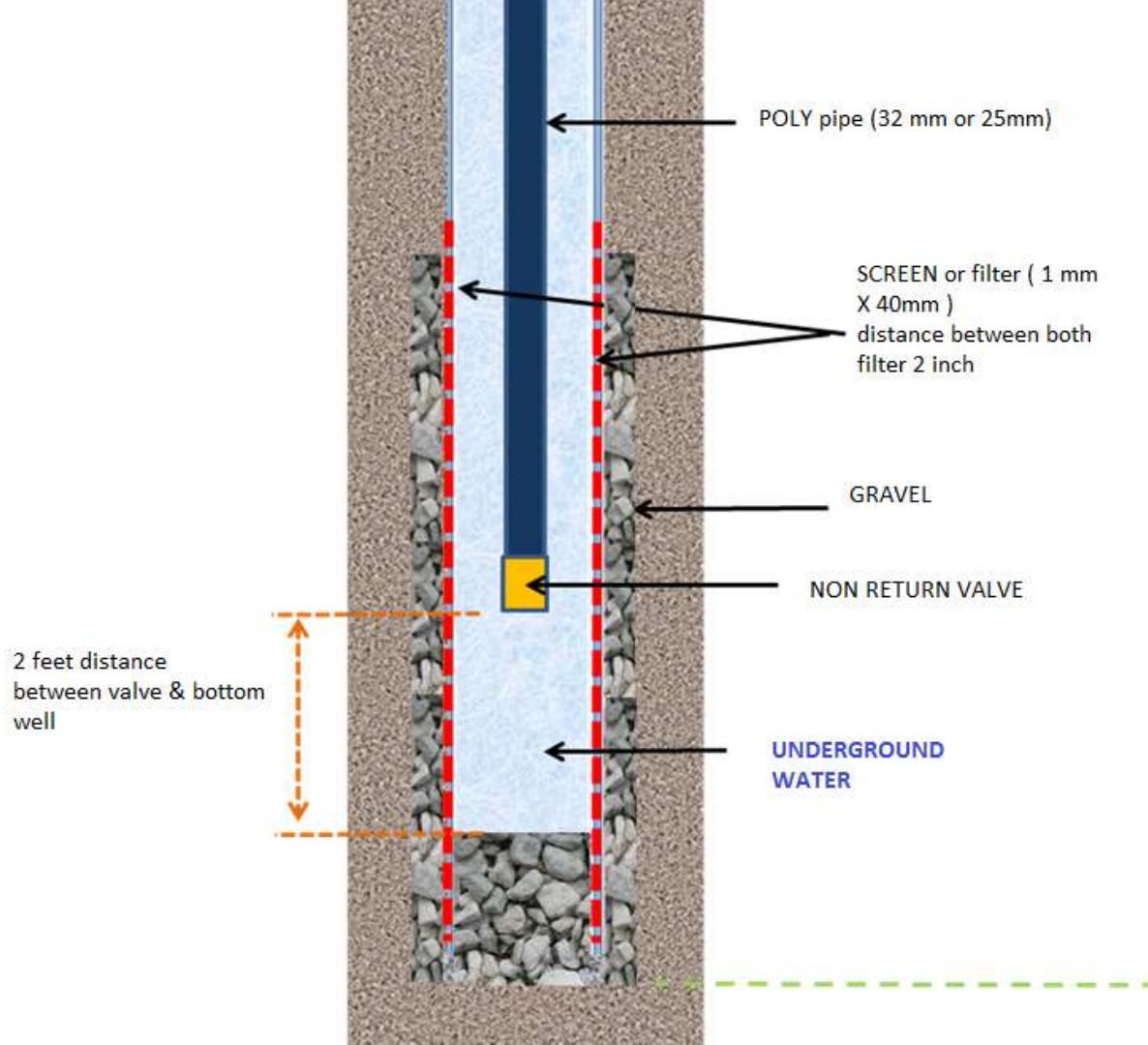


Auger



Borehole





# Well Construction

A variety of methods are used to construct water wells, depending on the geologic conditions and the intended use of the well.

## Types of well construction:

- a) Extending casing down the borehole through the upper loose sediment or rocks, but leaving the bottom portion of the borehole uncased. This type of well construction is usually used in hard, fractured rock. **(Partial Casing)**
- b) Extending casing down the borehole through sediment or rock and placing a well screen in the aquifer. This type of well construction is commonly used in unconsolidated sediment, such as sand and gravel **(Full Casing)**.

# Well Construction

## Typical well construction procedure:

- 1. Drilling Operations** - Drilling methods vary widely and range from digging by hand to the use of very technical and expensive drilling rigs. The rig is set up over the prospective well location and drilling continues until the desired depth has been reached.
- 2. Installing the Casing and Screen** - Once the desired depth of the borehole has been reached, casing and screen will be installed. Casing can be made of different materials, such as steel or plastic, and comes in various diameters and lengths.
- 3. Installing an Artificial Filter Pack** - For some well designs, it is necessary for an artificial filter pack to be placed around the screen. This operation takes place before grouting or sealing the well. The filter pack consists of graded sand or gravel, which is placed around the well screen. The filter pack removes or filters unwanted fine particles from the formation that would otherwise find a way into the well.
- 4. Grouting the Well** - Grouting a well involves filling the space between the casing and borehole wall with slurry of cement or clay. This is done to seal the area between the casing and borehole wall to prevent downward leakage of contaminants from the surface

# Well Development

**Well development** is a procedure intended to maximize the well yield. During the drilling operation, damage to the formation or aquifer occurs. This happens when the drill bit cuts through the rock or sediment leaving behind small pieces of rock or sediment that may plug the well screen and reduce the yield of the well. Also, during the drilling operation, different fluids may be introduced to the borehole to remove cuttings and to prevent it from collapsing.

**There are two main reasons for well development:**

- 1) Repair damage done to the formation during drilling, and to remove unwanted fluids, so that the natural properties of the aquifer are restored; and
- 2) Change the physical properties (porosity and permeability) of the aquifer near the borehole so that water will flow more freely into the well.

# Well Development

## Well Development Methods:

- 1) **Air Development by Surging and Pumping** - In air surging, air is injected into the well to lift the water to the surface. As it reaches the top of the casing, the air supply is shut off, allowing the aerated water column to fall thus forcing water in and out of the screen
- 2) **High-Velocity Jetting** - The jetting procedure consists of operating a horizontal water jet inside the screen so that water shoots out through the screen openings. Jetting with air is an alternative to water jetting
- 3) **Mechanical Surging** - Mechanical surging is another method of development which forces water to flow into and out of a screen by operating a plunger up and down in the casing.
- 4) **Over pumping** - It is pumping at a higher rate than the well will be pumped when put into service
- 5) **Backwashing** – Reversing direction of flow through the screen openings that will agitate the sediment, remove the finer fraction, and then rearrange the remaining formation particles

**Over pumping and Backwashing** are widely used.